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# The Snare-Assisted Technique for Transcatheter Coil Occlusion of Moderate to Large Patent Ductus Arteriosus: Immediate and Intermediate Results

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**OBJECTIVES** The purpose of this study was to evaluate the feasibility, safety and efficacy of using a snare-assisted technique to coil occlude the moderate to large size patent ductus arteriosus (PDA).

**BACKGROUND** Transcatheter occlusion of small PDAs using Gianturco coils is safe and effective. However, in larger size PDAs and/or those with short PDA length, the procedure still carries risks of coil embolization, incomplete occlusion and failure to implant the coil.

**METHODS** From January 1994 to June 1997, the records of 104 consecutive snare-assisted coil occlusions of moderate to large PDAs (minimum diameter >2.0 mm) were reviewed. Immediate and intermediate outcomes including complete and partial occlusion, failure to implant and complications were analyzed with respect to ductal type and size.

**RESULTS** Patient age ranged from 0.1 to 70.1 years (median 3.3 years). Minimum PDA diameter ranged from 2.1 to 6.8 mm (mean 3.0 ± 0.9 mm). Angiographic types were A-62, B-13, C-6, D-14 and E-9. Using the snare-assisted technique, coil placement was successful in 104/104 patients (100%), irrespective of size or angiographic type. Immediate complete closure was observed in 73/104 (70.2%) and was related to smaller PDA size, but not to angiographic type. Complete closure was documented in 102/104 (98.1%) at 2- to 16-month follow-up. Successful closure was unrelated to PDA size or type. Coil embolization to the pulmonary artery occurred in 3/104 (2.9%) patients and was not related to PDA size or type. The need for multiple coils was found in 28/104 patients (26.9%), and was related to larger PDA size, but not to angiographic type.

**CONCLUSIONS** The snare-assisted delivery technique allows successful occlusion of moderate to large PDAs up to 6.8 mm, irrespective of angiographic type. This technique permits improved control and accuracy of coil placement, and facilitates delivery of multiple coils. (J Am Coll Cardiol 1999; 33:1710–8) © 1999 by the American College of Cardiology

Transcatheter occlusion of the small patent ductus arteriosus (PDA) using Gianturco coils has been shown to be safe and efficacious (1–9). It is generally accepted that small PDAs can be occluded with excellent results, but for both larger diameter and shorter length PDAs, failure to implant, coil embolization during delivery and residual shunts remain problematic (3,4,6,7).

The initial use of a transvenous nitinol snare to "hold" the coil during its delivery to the PDA was designed to reduce the risk of inadvertent coil embolization when the minimum PDA diameter was underestimated, the PDA was asymmetrically shaped or the vessel was very compliant (8,9). However, the approach was subsequently found to have important additional advantages: improved control of the coil throughout the procedure, the ability to make fine adjustments in coil position, the ability to test coil stability before release, and the ability to remove a suboptimally placed coil without releasing it into the circulation. This study reports the immediate and intermediate term outcomes for coil occlusion of moderate to large PDAs (>2.0 mm) using the snare-assisted technique.

## METHODS

The records of 183 consecutive patients who underwent snare-assisted coil occlusion of a PDA between January 1994 and June 1997 were reviewed. These patients constitute the combined experience of the two authors. During

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**Abbreviations and Acronyms**

LPA = left pulmonary artery
MPA = main pulmonary artery
PDA = patent ductus arteriosus

this interval, three other patients with a PDA underwent cardiac catheterization, but did not undergo attempts at coil occlusion because of an excessively large type C (tubular) PDA (two with a minimum diameter of 10 mm and 12 mm and one with an 8-mm diameter and coexisting coarctation of the aorta). These three patients were referred for surgery.

All patients with a PDA minimum diameter >2.0 mm, as measured on the lateral projection of an aortic angiogram, were identified for our study group. The study group was further divided into three subgroups: group I (minimum PDA diameter of 2.1 to 3.0 mm), group II (minimum diameter 3.1 to 4.0 mm) and group III (minimum diameter >4.0 mm). The patients were also grouped by angiographic types (A–E) based on Krichenko's criteria to assess the impact of ductal type on outcome (10). Immediate and intermediate follow-up results were analyzed for each group. The outcomes of the study group were also compared with those of our patients with minimum PDA size ≤2.0 mm (small PDA group).

**Coil occlusion technique.** Both authors have previously presented the snare-assisted technique for coil delivery (8,9). Through experience with the technique, several important modifications have been made since the original descriptions:

Using a Cardiomarker catheter (USCI, Billerica, Massachusetts) or a Magic guide wire (Medi-tech, Watertown, Massachusetts) as a measurement reference, the minimum PDA diameter, aortic ampulla dimension and ductal length are measured (Fig. 1). A Berenstein catheter (Medi-tech) is advanced in retrograde fashion through the PDA into the main pulmonary artery (MPA), and is snared with a 4-F, 10-mm diameter nitinol snare (Microvena Corp., White Bear Lake, Minnesota) advanced from the femoral vein. A Gianturco coil (Cook, Bloomington, Indiana) is selected with a helical diameter 1.6 to 2 times the minimum PDA diameter and with a length sufficient to form at least three loops, and is advanced through the Berenstein catheter. Approximately 1/4 loop of coil is extruded out of the catheter. The snare is loosened and withdrawn slowly to "grab" the distal 2 to 3 mm of the extruded coil tip, which is devoid of Dacron fibers (Fig. 2). Snaring more than this length risks entangling the snare in the Dacron fibers of the coil, and may make subsequent coil release more difficult. The Berenstein–coil–snare unit is adjusted as a single unit so that only the snare and the extruded coil segment remain in the MPA. The remaining coil loops are then delivered into the aortic ampulla (Fig. 3). By placing gentle traction on the snare, the coil position is adjusted so that only 1/3 loop and no more than one loop is pulled into the MPA (Fig. 4). This action often results in wedging of coil loops further into the aortic ampulla, which improves ductal occlusion and minimizes coil protrusion into aortic flow (compare coil position relative to tracheal air column in Fig. 3 and 4). By minimizing the amount of coil in the MPA, the risk of branch pulmonary artery impingement is also

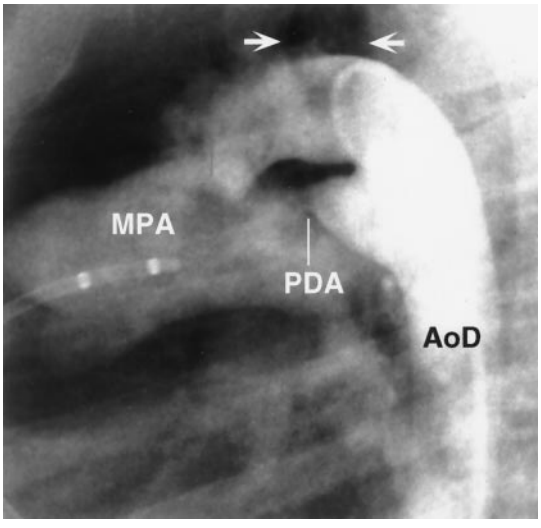


**Figure 1.** A descending aortogram in lateral projection demonstrates a type A patent ductus arteriosus (PDA) with a minimum diameter of 3.1 mm located just anterior to the tracheal air column (between **white arrows**). This air column is highlighted in Figures 1 through 6 with white arrows and serves as an important reference landmark for coil positioning. A catheter with a 10-mm marker is placed in the main pulmonary artery (MPA) for measurement references. (AoD = descending aorta.)

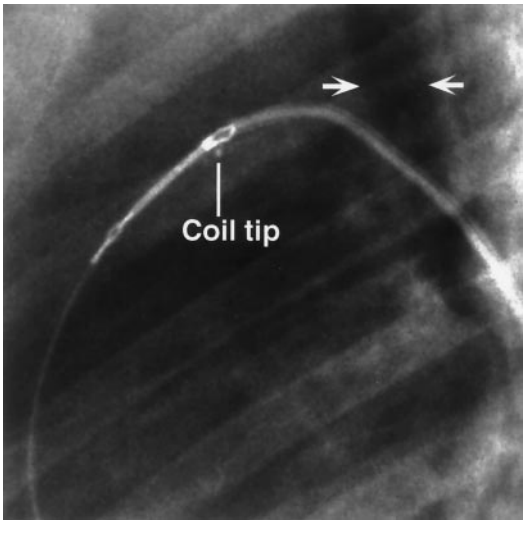


**Figure 2.** A 1/4 loop of the coil is extruded out of the Berenstein catheter. The snare is loosened and withdrawn gently so that it slides off the catheter onto the "hook" of the loop to snare the coil. To minimize entanglement with Dacron fibers on the coil, no more than 2 to 3 mm of the coil tip should be snared. **White arrows** = tracheal air column.

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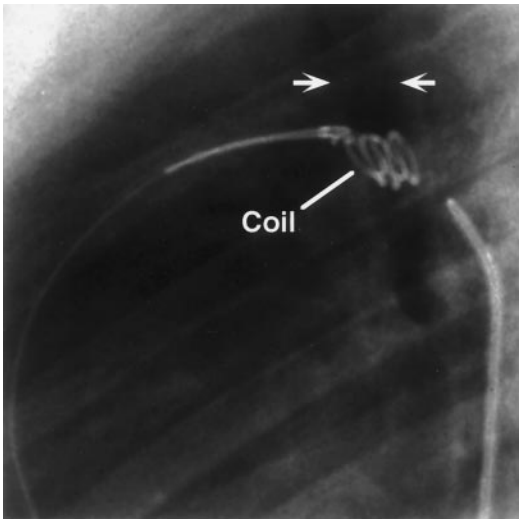


**Figure 3.** The snare–coil–Berenstein unit is adjusted so that only the proximal coil tip is in the main pulmonary artery and the rest is in the descending aorta. The entire coil is then delivered out of the Berenstein into the descending aorta, and the coil loops reform within the aortic ampulla and descending aorta. The tracheal air column (between **white arrows**) is critical for proper coil delivery.

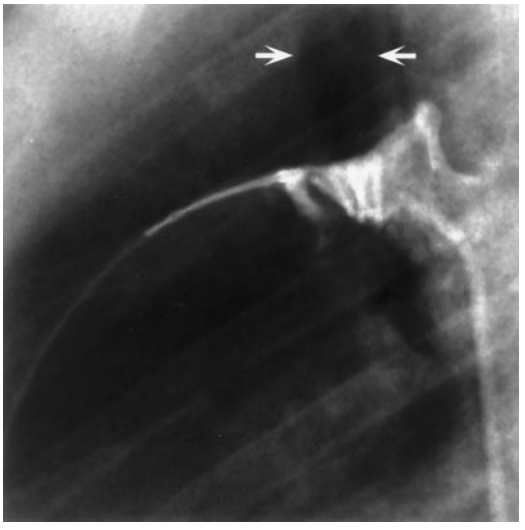

**Figure 5.** Once the coil position is optimal, injection of contrast medium through the Berenstein catheter immediately after coil implant is useful to assess residual shunting and to confirm coil position in relationship to the pulmonary artery and aortic ampulla before snare release. **White arrows** = tracheal air column.

minimized. A hand injection of contrast is performed through the Berenstein catheter at the aortic ampulla before snare release (Fig. 5). If the coil appears to be in a good position with no residual shunting, the snare is opened to release the coil (Fig. 6). If the coil appears to protrude into the aortic flow, the snare can pull additional coil into the MPA. If there is residual shunting more than trace to small, the Berenstein can be manipulated back through the PDA while the snare is still "holding" the implanted coil to prevent inadvertent embolization. Once the Berenstein is safely through the PDA, the initial coil is released, the Berenstein is resnared and a second coil is delivered in a similar fashion. The second coil should have a smaller diameter than the first, so that it can "nest" inside the larger

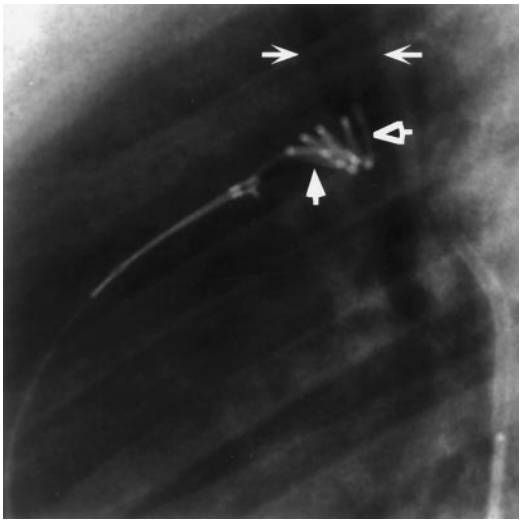

**Figure 4.** The coil position is adjusted by placing gentle traction on the snare. Note this maneuver results in wedging of the coil into the conical shaped ampulla for better occlusion. Comparing the coil position to the tracheal air column in Figure 3, note also the coil has been pulled more anteriorly by the snare. The first proximal loop **(solid white arrowhead)** is oriented parallel to the segment of the ductus that contains the minimum diameter as it enters the pulmonary artery. The horizontal alignment of the proximal coil loop to the ductus increases its occlusive abilities. The most distal coil loop **(open arrowhead)** maintains a perpendicular alignment to the ductus inside the aortic ampulla and will prevent the coil from embolizing through the ductus into the main pulmonary artery. **White arrows** = tracheal air column.

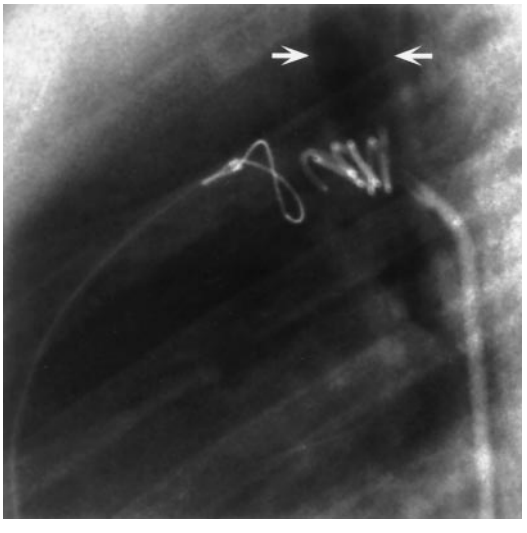

**Figure 6.** Coil is released from snare. Note only 1/4 coil loop is used to anchor the coil in the main pulmonary artery side, minimizing any risk of impingement of left pulmonary artery flow. **White arrows** = tracheal air column.

**Figure 7.** Final descending aortogram to evaluate for residual shunting. Note the snare-assisted technique in coil delivery has permitted most of the coil to be placed on the aortic side where it participates in occlusion.

coil where most residual shunts seem to occur. A repeat right heart sweep is performed to rule out residual left to right shunt and left pulmonary artery impingement by the coil. A final descending aortogram is performed 10 to 15 min after coil delivery (Fig. 7). Antibiotics are administered (cefazolin 25 mg/kg), and continued for two to three doses. All study patients received an echocardiogram to assess residual shunting within 24 h of the procedure.

**Statistical analysis.** Statistical comparisons of proportions were analyzed using either a chi-square or Fischer exact test. A simple *t* test was used for comparing populations. A one-way analysis of variance test was used for comparing multiple populations. Statistical significance was calculated using an automated statistical software package (SigmaStat 2.0 for Windows 95, Jandel Scientific, San Rafael, California). A p value of 0.05 was chosen for statistical significance in all cases.

## RESULTS

**Patient profile.** Of 183 consecutive patients reviewed, 104 met the criteria for our study group (PDA diameter >2.0 mm); 78 patients fell into the small PDA group (PDA diameter ≤2.0 mm) (Table 1). One patient, in whom a Rashkind device was implanted previously, had several small residual "jets." As a result, the minimum PDA dimension could not be measured and the patient was excluded from the study. The study group had a median age of 3.3 years (range 0.1 to 70.1 years), a median weight of 15.3 kg (range 3 to 73 kg) and a mean minimum PDA diameter of 3.0 ± 0.9 mm (range 2.1 to 6.8 mm). There were 62 patients in group I (range 2.1 to 3.0 mm, mean = 2.4 ± 0.2), 27 patients in group II (range 3.1 to 4.0 mm, mean = 3.5 ± 0.3) and 15 patients in group III (range = 4.1 to 6.8 mm, mean = 4.7 ± 0.7). The distribution of the angiographic types was type A, 62; type B, 13; type C, 6; type D, 14; and type E, 9.

**Coil implantation.** The results are summarized in Table 1. Using the snare-assisted technique, coil implantation was successful in 104/104 study group patients (100%), irrespective of ductal size or type.

**Immediate closure.** Immediate complete closure was demonstrated in 73/104 (70.2%) by angiography and/or echocardiography within 24 h in the study group. Immediate complete closure was significantly greater in the small PDA group (96.2%, $p < 0.001$) compared with the study group. Although no statistical difference in immediate complete closure rate was found between groups I, II or III, the rates trended downward as PDA size increased: group I, 77.4% (48/62); group II, 63.0% (17/27), and group III, 53.3% (8/15). There was no statistical difference in immediate complete closure rate based on angiographic type (Table 2):

**Table 1.** Summary of Results Using Snare-Assisted Technique on Moderate to Large PDAs

| | Groups (PDA Minimum Diameter) | | | |
|---|---|---|---|---|
| | I (2.1–3.0 mm) | II (3.1–4.0 mm) | III (>4.0 mm) | Total |
| Mean minimum diameter (mm) | 2.4 ± 0.2 | 3.5 ± 0.3 | 4.7 ± 0.7 | 3.0 ± 0.9 |
| n | 62 | 27 | 15 | 104 |
| Failure to implant | 0 | 0 | 0 | 0 |
| Immediate complete occlusion | 77.4% (48/62) | 63.0% (17/27) | 53.3% (8/15) | 70.2% (73/104) |
| 2–16-mo F/U | 98.4% (61/62)* | 100% (27/27) | 93.3% (14/15)† | 98.1% (102/104) |
| Multiple coils | 9.7% (6.62) | 40.7% (11.27) | 73.3% (11.15) | 26.9% (28/104) |
| Coil embolization | 0 | 3 | 0 | 2.9% (3/104) |

*Includes one patient who underwent a second catheterization and one additional coil for complete closure of residual shunt.
†Includes two patients who underwent a second catheterization and one additional coil for complete closure of residual shunt.
F/U = follow-up; PDA = patent ductus arteriosus.

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**Table 2.** Complete Occlusion by PDA Types

| PDA Type | n | Immediate | 2–16-mo F/U |
|---|---|---|---|
| A | 62 | 41/62 (66.1%) | 61/62 (98.4%) |
| B | 13 | 10/13 (76.9%) | 12/13 (92.3%) |
| C | 6 | 4/6 (66.7%) | 6/6 (100%) |
| D | 14 | 11/14 (78.6%) | 14/14 (100%) |
| E | 9 | 7/9 (77.8%) | 9/9 (100%) |
| Total | 104 | 73/104 (70.2%) | 102/104 (98.1%) |

Abbreviations as in Table 1.

A, 66.1% (41/62); B, 76.9% (10/13); C, 66.7% (4/6); D, 78.6% (11/14), and E, 77.8% (7/9).

**Follow-up closure results.** At 2- to 16-month follow-up, echocardiogram demonstrated complete occlusion in 102/104 (98.1%). Three of these patients had undergone a second catheterization to close an audible residual shunt, at which time total occlusion was achieved using a single coil. The two remaining patients with a trace residual shunt by echocardiogram have no audible murmurs. One patient is only a few months out from the procedure and has not had a follow-up echocardiogram. The other patient, at 12 months after coil occlusion, is waiting to see if late spontaneous closure will occur. One patient was in group I (PDA diameter 2.7 mm), and one in group III (4.3 mm). Of the three patients who underwent recatheterization, one was in group I (2.4 mm), and two were in group III (4.1 mm, 5.0 mm). With respect to angiographic type, two of these five patients were type A, and three were type B. Late closure results of the study group (98.1%) are similar to those of the small PDA group (98.7%) (Table 3).

**Use of single or multiple coils.** Multiple coils were implanted in 26.9% (28/104) of our study group. Two coils were used in 23 patients, 3 coils in 2 patients and 4 coils in 1 patient with a 6.8-mm PDA. There was a significant relationship of multiple coil use with increasing PDA size. In the small PDA group, multiple coils were used in only 2.6% (2/78) ($p < 0.001$). Group I patients received multiple coils in only 9.7% (6/62) of procedures ($p < 0.03$, compared with the study group as a whole); both group II (40.7%, 11/27; $p < 0.02$) and group III (73.3%, 11/15; $p < 0.001$) patients received multiple coils more frequently than group I. In the study group, the mean PDA minimum diameter in which a single coil was implanted was 2.8 ± 0.6 mm compared with 3.8 ± 1.1 mm in the patients with a multiple coil closure ($p < 0.001$). The largest PDA to have immediate complete closure with a single coil was 4.9 mm in diameter.

We found no significant relationship between multiple coil use and angiographic type. However, comparison between types A and D approached a statistical difference ($p = 0.067$).

**Coil embolization.** There were no systemic embolizations and 3/104 (2.9%) coil embolizations to the pulmonary arteries using the snare-assisted technique. There were no additional embolizations in the small PDA group. All three coil embolizations occurred in the early part of the author's experience. All embolized coils were retrieved with subsequent complete occlusion of the PDA. Embolizations were unrelated to PDA size or angiographic PDA type.

**Left pulmonary artery (LPA)/aortic stenosis secondary to coil placement.** At immediate postcatheterization echo, there was an increase in Doppler flow velocity at the origin of the LPA (<2.1 m/s) in 4/104 patients, even though no significant pressure gradient was found during the postcoil right heart sweep. This increase in velocity resolved in 3/4 patients by the time of the 6-month follow-up. The one patient with ongoing echo evidence of increased velocity at the LPA takeoff had a quantitative lung perfusion scan which revealed 62% of pulmonary flow to the right lung and 38% to the left lung. There was no Doppler evidence of aortic impingement in any patient.

**Coil removal before release for suboptimal placement.** The snare was used to remove 1 to 7 coils in 28/104 (26.9%) patients before snare release. The indication for coil removal included: excessive coil loops slipping through the PDA into the MPA, coil protrusion into LPA or aortic lumen and inability to free coil from snare in two patients. Within the study group, there was no statistically significant relationship of coil removal and increasing PDA size, although removal tended to occur more often in larger PDAs: 16% of group I, 29% of group II and 33% of group III. In contrast,

**Table 3.** Comparison of Study Group to Small PDA Group

| | Study Group | Small PDA Group | p Value | Total Experience |
|---|---|---|---|---|
| Mean minimum diameter (mm) | 3.0 ± 0.9 | 1.3 ± 0.4 | < 0.001 | 2.3 ± 1.1 |
| n | 104 | 78 | | 182 |
| Failure to implant | 0 | 0 | NS | 0 |
| Immediate complete occlusion | 70.2% (73/104) | 96.2% (75/78) | < 0.001 | 81.3% (148/182) |
| 2–16-mo F/U | 98.1% (102/104) | 98.7% (77/78) | NS | 98.4% (179/182) |
| Multiple coils | 26.9% (28/104) | 2.6% (2/78) | < 0.001 | 16.5% (30/182) |
| Coil embolization | 2.9% (3/104) | 0 | | 1.6% (3/182) |

only 5% of coils were removed in the small PDA group ($p < 0.02$).

There was no statistically discernible relationship between the need for coil removal and angiographic type: type A, 32%; type B, 30%; type C, 17%; type D, 16%, and type E, 11%.

## DISCUSSION

Experience with coil occlusion of the PDA has grown dramatically over the past few years (1–9). A variety of reported techniques have excellent results in closing small PDAs. The PDA Coil Registry, representing some 46 institutions, reported a large series of 535 patients with a median minimum PDA diameter of 2.0 mm. Complete occlusion was achieved in 75% within 24 h, with a 20% residual shunt rate and a 5% rate of failure to implant a coil. There was a significant relationship between size and success rate for the procedure. The average PDA minimum diameter in the complete closure group was 1.9 mm, the diameter for "partial success" was 2.4 mm and the mean diameter for failure to implant was 2.9 mm. There was an overall 14.9% coil embolization rate to either the pulmonary or the systemic circulations. The Registry demonstrated a significant relationship between failure of coil implantation and angiographic ductal type B.

More recently, studies from single institutions have shown an improvement in outcome for larger PDAs. Hijazi and Geggel reported a series of 33 patients with a mean minimum PDA diameter of 2.8 mm (4). Using a prograde (transvenous) approach, complete occlusion was achieved in 91% of patients. However, multiple coils were used in 55% and left pulmonary artery obstruction was seen in 6% of patients, who received five coils each. Failure to implant and coil embolization rates were 6% and 9%, respectively. Owada et al. recently reported a series of 16 patients with even larger PDAs (minimum diameter >3.5 mm) (7). Using primarily larger caliber coils (0.052-in. [0.132 cm] gauge), they documented complete occlusion in 73% of patients in whom coils were successfully implanted. However, multiple coils were used in 36%, and the rates of implantation failure and coil embolization were 31% and 43%, respectively.

**Closure results.** Using the snare technique in our study group of moderate to large PDAs, immediate complete closure was seen in 70.2%, comparable to the Registry closure rate, despite a statistically larger mean PDA diameter in our study group ($p < 0.05$).

With respect to late complete closure at follow-up, the snare patients compare favorably with a nonrandomly selected subset of the Registry patients (5). Ninety-nine of 104 in our study group (95.2%) had complete closure at last follow-up without reintervention, in contrast to 339/371 (91%, $p = 0.015$) in the Registry, which did not include the 5% of patients in whom there was failure to implant a coil. Our late complete closure rate increases to 97.8% (178/182) when the small PDA group patients are included, and increases further to 98.9% (180/182) when three patients with a residual shunt underwent repeat catheterization for an additional coil. This is comparable to data reported by Shim et al. in which 75 patients received coils for a PDA (6). Their actuarial analysis estimated complete closure in 94% at 20 months and reintervention in 7% of patients. However, the mean minimum ductal diameter of their study group was much smaller ($1.6 \pm 0.8$ mm) as compared with that of our group ($3.0 \pm 0.9$ mm).

**Coil embolization.** Embolization of the coil was significantly lower in our series than in the PDA Coil Registry (2.9% vs. 14.9%, $p < 0.001$), but was not eliminated entirely. Our embolization rate drops to 1.6% when analyzing all 182 snare patients.

The three cases of coil embolization that occurred were due to technical errors early in the authors' learning curve and lead to refinements in the technique. In one patient, at the time of coil release, the snare appeared disengaged from the coil by fluoroscopy. But radioluscent Dacron fibers were still adherent to the snare. Since this was not appreciated, withdrawal of the snare resulted in coil embolization into the LPA. In subsequent cases, after separation of the snare and coil, instead of withdrawing the disengaged snare, the snare delivery catheter is advanced over the snare to the coil tip. In the event that Dacron fibers remain adherent to the snare, the coil position is stabilized by the catheter as the snare is withdrawn into its lumen. Once the snare is withdrawn a few centimeters, the delivery catheter may be removed. Snaring only the first 2 to 3 mm of the coil where there are no Dacron fibers also minimizes this risk.

In the second patient, a coil was implanted but dislodged during advancement of the Berenstein catheter across a residual shunt in an attempt to place a second coil. This complication prompted us to maintain the snare on the first coil during passage of the Berenstein catheter in subsequent cases.

In the third patient, insufficient coil was snared. During an attempt to remove the coil, which was suboptimally placed, the snare slipped off the coil. Since that event, sufficient coil length (2 to 3 mm) is snared to result in a visible "bend" to avoid slippage during traction. However, excessive tension on the coil should be avoided, since that may cause a "kink" in the coil resulting in more difficult release. These three complications occurred only once each, early in our experience (first 13% of patients).

**Multiple coils.** The use of multiple coils is preferable to repeat catheterization for closing residual shunts, though most authors cite the use of multiple coils as a risk factor for coil impingement on adjacent structures and for coil embolization (3,6,8). It has been our practice to place additional coils for anything more than trace residual shunting. However the need for additional coils, during the initial procedure, may be reduced if the first coil is optimally positioned.

Our study group had an equivalent rate of multiple coil

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use compared to the PDA Coil Registry (27% vs. 26%), despite our significantly larger mean PDA size. Comparison of our entire population of 182 patients to the Registry showed that the snare-assisted closures had a significantly lower rate of multiple coil use (15% vs. 26%, $p = 0.005$).

**Coil impingement on adjacent structures.** Most authors screened prospectively for impingement of the coils on adjacent structures as a result of prior experience with the Rashkind Occluder (11–15). To date, there has been no significant problem with aortic arch obstruction secondary to coil position in any series. Some LPA impingement by the coil, with either frank stenosis and/or increased flow rates by Doppler, have been noted in some patients by all authors. Moore et al. found Doppler evidence of LPA impingement in 10/29 patients (3). The findings of others were very similar to our own, with no evidence of LPA stenosis at catheterization, but mild increased Doppler flow velocity in a few patients (6,16). Hijazi and Geggel reported 2/31 patients with true LPA stenosis secondary to coil impingement on the lumen (4).

**Patent ductus arteriosus angiographic type.** Angiographic type B of Krichenko was cited as a risk factor for procedural failure in the PDA Coil Registry and in other series (3,4). Using the snare-assisted technique, we found no relationship of this angiographic type to procedural failure, to incomplete closure or to multiple coil use.

**Advantages of the snare technique.** Use of the nitinol snare to "anchor" the coil during its delivery and to adjust coil position after delivery has several theoretical advantages.

1. The snare-assisted technique permits simple coil retrieval, rather than embolization, when operator error is encountered such as underestimation of the minimum PDA diameter or inaccurate coil positioning. Because there is a learning curve to PDA occlusions, the snare may act as a "safety net," resulting in less anxiety for the inexperienced operator. If embolization is reduced or eliminated with the snare technique, the patient is spared additional sedation and radiation time during coil retrieval.
2. After coil delivery, the snare may be used to adjust suboptimal coil position. Gentle traction often results in further wedging of the coil loops into the aortic ampulla. In those cases when the distal coil loops protrude into the aortic flow, the coil can be pulled further into the ampulla/MPA (compare Fig. 3 and 4). This is particularly useful in the more difficult type B ductus where the aortic ampulla is shallow.
3. By "anchoring" the coil with a snare during delivery, less coil loop is required on the MPA side. In smaller children, less coil in the MPA reduces the risk of LPA impingement. At the same time, more coil left in the aortic ampulla results in improved occlusion. This may be the primary mechanism by which our high rate of success was achieved.
4. Early authors recommended the use of a coil with a helical diameter twice the minimum ductal diameter (1–3). Since the snare rather than a coil loop anchors the coil during its delivery, the snare-assisted delivery allows attempted closure with smaller coils without risk of embolization. The advantage of a smaller coil is that the Dacron fibers of the smaller coils overlap its center better than those of the larger coils (Fig. 8A). Thus, while the larger coil may reduce risk of embolization, its occlusive abilities are less. The PDA Coil Registry first reported a significant relationship between smaller coil size and successful complete closure. The larger coils are less compact (Fig. 8B), and may protrude into the MPA and/or aorta. We have found that by using the snare technique, coil helical diameter as small as 1.6 times the minimum ductal diameter can be used. Traction on the snare allows testing of coil stability in the ampulla before release. The new larger gauge coils (0.052 in. [0.132 cm]) are more compact, and initial reports of their use are promising (7).

**Disadvantages of the snare-assisted technique.** As with all techniques, there are some disadvantages to the snare-assisted approach. Some of the perceived shortcomings of the technique are real, but should diminish with operator experience.

1. During snare adjustment of the coil position, excessive coil loops may be inadvertently pulled into the MPA, necessitating coil removal. In our series, although 28/104 (27%) patients required removal of a suboptimally positioned coil, 20 were in the first 50% of the series, and only three retrievals were required in the last 25% of the cases. Some of these unstable coils would have been at risk for embolization if the snare had not been used.
2. Coil release may be difficult for the inexperienced operator. Release is best achieved by pushing the snare forward into the LPA rather than withdrawing away from the coil. As the "snared" coil is oriented with the open end of the loop facing posteriorly, this maneuver lessens the risk of coil embolization or inadvertent coil movement. The recent addition of a torque device to the snare catheter also facilitates release. Extruding no more than 1/4 loop of coil and snaring only 2 to 3 mm from the coil tip, as mentioned earlier, is critical for smooth release.
3. The use of the snare adds an additional $135 to the cost of the procedure. Based on our results, improved implantation rate, higher rates of complete closure and fewer coils (and catheters) needed for closure should render the snare-assisted technique more cost-effective, especially for larger and/or type B PDAs. If embolization occurs, a snare will be required anyway.
4. The snare technique has been criticized for increasing the length and complexity of the procedure. The total fluoroscopic time needed to snare and release the coil is no more than 15 min. This is comparable to the average fluoroscopy times reported in the initial series of Hijazi and Geggel (24 min) and Moore et al. (12.9 min) (3,4).

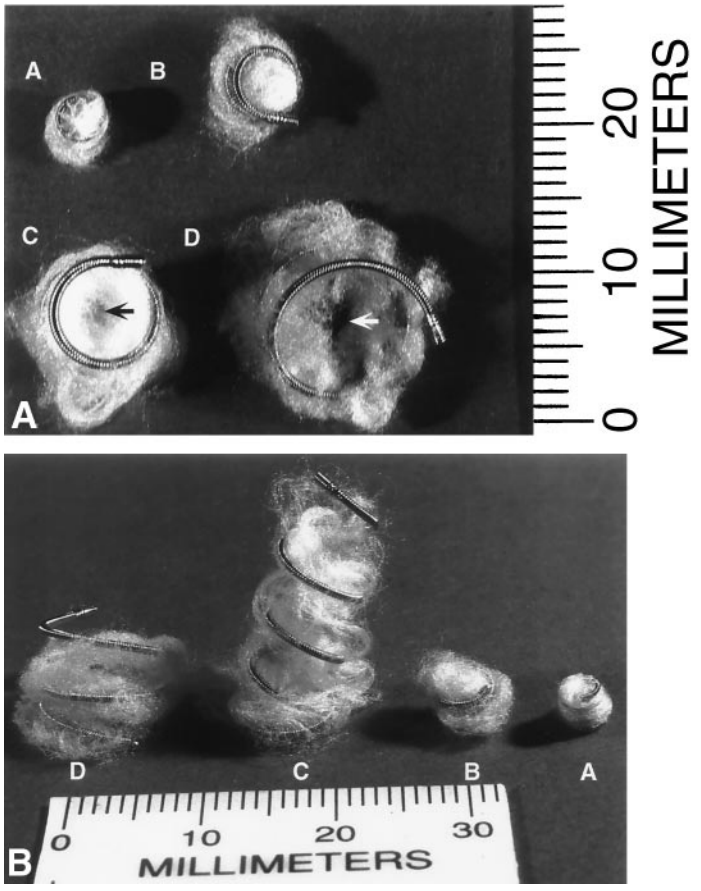


**Figure 8. (A)** Four coils of different dimensions. A, 0.035-in. (0.089 cm) gauge, 4-cm length, 3-mm diameter; B, 0.038-in. (0.097 cm) gauge, 5-cm length, 5-mm diameter; C, 0.038-in. (0.097 cm) gauge, 10-cm length, 8-mm diameter, D, 0.038-in. (0.097 cm) gauge, 8-cm length, 10-mm diameter. Notice the centers of the 3- and 5-mm diameter coils are completely covered by Dacron fibers. In contrast, the centers of the 8- and 10-mm diameter coils are incompletely filled by Dacron fibers, and one can see through them **(arrows)**. **(B)** Side view of the four coils. Note the smaller coils are more compact compared with the larger coils, which have a much larger side profile and can result in coil protrusion into the aorta or pulmonary artery.

**Conclusions.** In conclusion, the snare-assisted technique used for coil occlusion of the moderate to large patent ductus arteriosus is safe and effective. The use of the snare eliminates PDA type from consideration as a risk factor for failure. This technique reduces the risk of coil embolization during delivery and permits more "accurate" coil positioning, reducing the risk of implantation failure, late residual shunting and coil protrusion into the pulmonary and aortic flow as well as reducing the need for multiple coils to achieve complete occlusion. We have not found the snare-assisted technique to be associated with longer procedural times or additional radiation exposure. The use of this technique should be considered for larger PDAs or those perceived to be at high risk based on morphology.

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